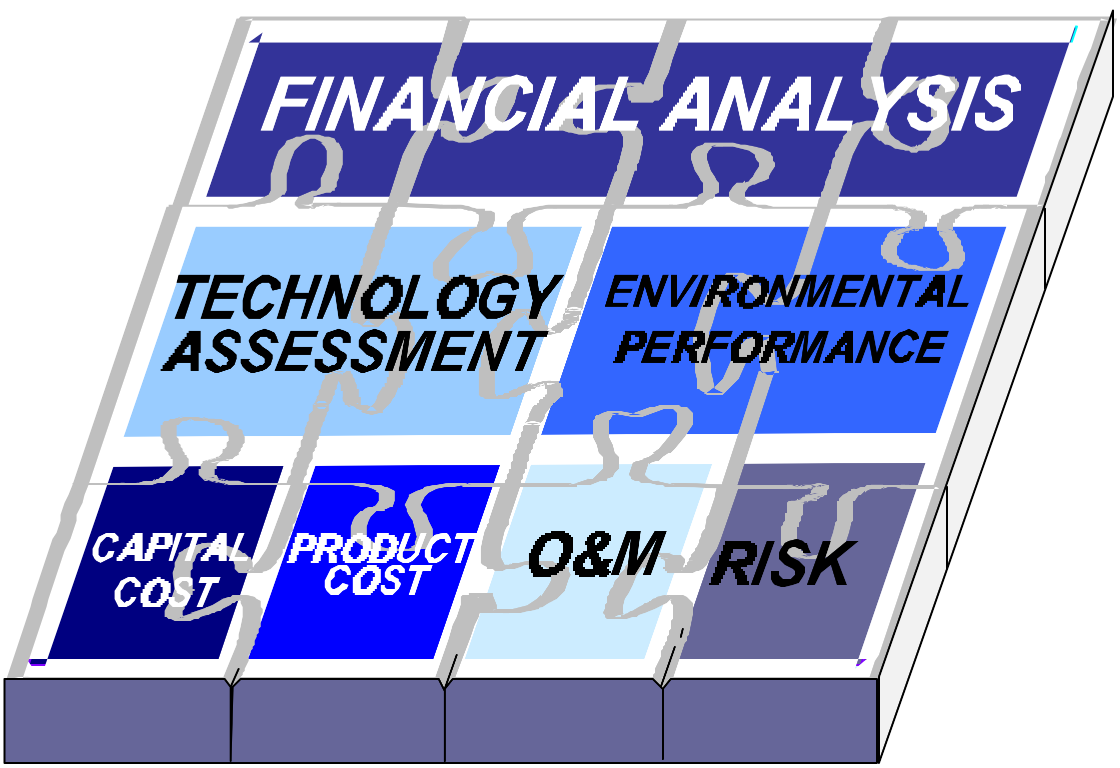
EXECUTIVE SUMMARY

Clean Coal Technology Evaluation Guide

Final Report

December 1999



INTRODUCTION

The energy industry is undergoing unprecedented regulatory change providing new challenges and opportunities in the competitive power market. With competition from Independent Power Producers, Non-Utility Generators, and competing utilities, generation investment is based on market demand, competitive price structure, and technology options. This investment involves various decision hurdles in a risky environment where generation will be a low-margin business dominated by low-cost providers. The generation decision-maker is faced with a multitude of technology options, with the most advanced coal-based concepts under development and demonstration in the U.S. Department of Energy's Clean Coal Technology (CCT) Program. Benefits of each are tied to the needs of the generator as dictated by economic and environmental criteria. The technical challenge is integrating the attributes of the selected technology to achieve investors' market, economic, and performance goals.

Clean coal technologies provide business opportunities that generation executives must understand and take advantage of in the new era of competition. Under this new business climate there is a need for providing a decision-maker with information and methods of evaluating competing technologies that are more applicable to today's market conditions. Technology developers, financial investors, and project developers share in the need for these data in order to evaluate investments in power generation upgrades and additions to their utility systems. With the data forthcoming from the CCT program – a partnership of the U.S. Department of Energy and industry – design, cost, and operational information is now becoming available to assist in performing the necessary evaluations.

The U.S. Department of Energy has developed this Clean Coal Technology Evaluation Guide to provide a consistent basis for communication of CCT data. Contained in this guide are the technical, economic, and environmental performance data on CCTs for advanced power generation applications, along with comparative analyses of competing technologies. Data are presented in a format to assist in the selection of power generation options for application starting in the year 2005. The approach presented in meeting the needs of a decision-maker consists of applying lessons learned in the CCT programs to update technical, cost, and environmental performance data on selected CCTs in a comparative analysis with other state-of-the-art technology options. Through the use of this information, and the methods defined for comparative analysis, a decision-maker can determine appropriate strategies for industry to promote market acceptance of CCTs. The initial slate of CCTs under consideration includes integrated gasified combined cycle and pressurized fluidized-bed combustion, with comparisons to conventional pulverized coal and natural gas combined cycle technologies.

The objectives in developing this guide were to:

- Develop updated technical, cost, and environmental performance data for advanced CCTs with comparative analysis to conventional power generation options.
- Provide a consistent basis for evaluating the technical, cost, and environmental performance for clean coal technologies.
- Provide decision-makers involved in power generation technology selection with information necessary to evaluate advanced power generation technologies for commercial application.

The CCT Program, a model of government and industry cooperation, responds to the Department of Energy's (DOE) mission to support competitive and efficient electric systems. With 23 of the 40 active projects having completed operations, the CCT Program has yielded clean coal technologies (CCTs) that are capable of meeting existing and emerging environmental regulations and competing in a deregulated electric power marketplace.

The success of the CCT program ultimately will be measured by the contribution the technologies make to the resolution of energy, economic, and environmental issues. These contributions can only be achieved if the public and private sectors understand that CCTs can increase the efficiency of energy use and enhance environmental performance at costs that are competitive with alternative energy options. The CCT Program is organized from a market portfolio perspective with projects placed in four major end use applications – environmental control devices, advanced electric power generation, coal processing for clean fuels, and industrial applications. A summary of the projects by category is shown below.

Application Category	No. of Projects
Environmental Control Devices	
SO_2 Control Technology	5
NOx Control Technology	7
Combined SO_2/NOx Control Technology	7
Advanced Electric Power Generation	
Fluidized-Bed Combustion	5
Integrated Gasification Combined Cycle	4
Advanced Combustion/Heat Engines	2
Coal Processing for Clean Fuels	5
Industrial Applications	5
Total	40

Information on the CCT projects and status can be viewed on the Clean Coal Technology Compendium at www.lanl.gov\projects\cctc.

GUIDE OVERVIEW

Volume I provides an overview of the key issues identified by power generation decision-makers including technical, economic, environmental, regulatory, and market issues. The key market issues affecting power generation decision-makers for the foreseeable future include:

- Deregulation of the utility industry
- Future energy demand
- Competition for new generation
- Open access to the transmission network
- Maintaining existing generation as long as possible
- Wholesale market clearing
- Costs of generation
- Access to capital

Stakeholder input and feedback on a preliminary listing of issues facing a decision-maker are presented, including the potential impacts from the deregulation of the utility industry, competition for new generation, and open access to the transmission network.

The CCTs considered for commercial viability in the evaluation's timeframe are introduced. CCT and conventional power systems evaluations are presented in a summary format to allow the reader to quickly obtain key decision process inputs. Brief power plant descriptions are provided with overall environmental and performance analyses, and capital and production costs for each technology.

Risk assessment on the capital cost components associated with each of the advanced power plant configurations is defined to identify an expected cost of pushing the technology from the developmental status to full commercialization by 2002. The approach, basis, and methods that were used to perform capital and production cost evaluations are provided in summary, along with technology evaluation results in a side-by-side format for technology performance, economics, and environmental comparison.

In addition to the technology evaluations, supporting data and information are provided in the Volume I appendices, covering environmental regulations, economic and financial analyses, development of capital cost sensitivity, and contacts within the manufacturing, power producers, and R&D communities.

TECHNOLOGY DESCRIPTIONS

A summary review of the four technology concepts follows, including integrated gasification combined cycle, pressurized fluidized-bed combustion, natural gas combined cycle, and subcritical pulverized coal. The economic viability of IGCC and PFBC plants is dependent upon the successful demonstration and commercialization of advanced technology systems. Accordingly, the IGCC and PFBC plant configurations described in this report utilize advanced gas cleanup concepts. The following table lists the featured components of the IGCC and PFBC plant configurations as well as those of the state-of-the-art competing technologies, pulverized coal plant and the natural gas turbine combined cycle.

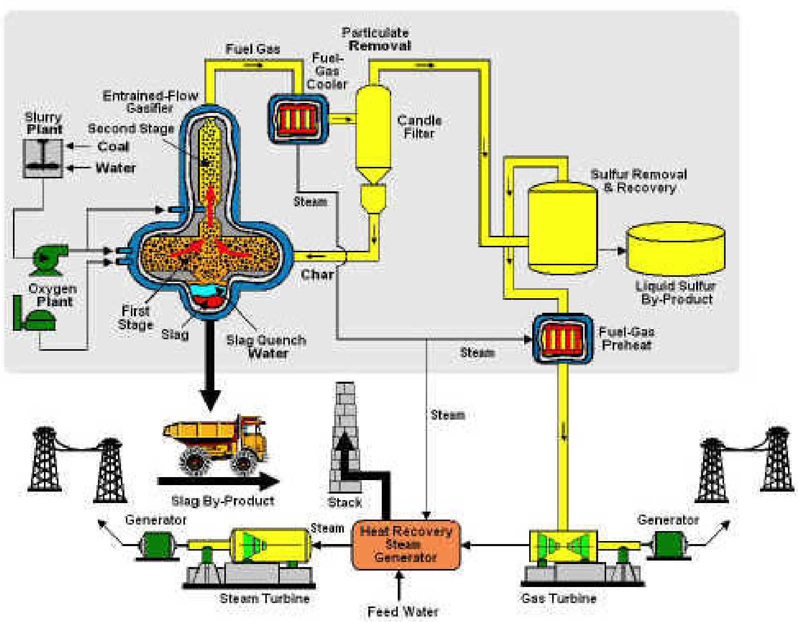
Summary Overview of the Plant Configurations

	IGCC Air-Blown	IGCC Air-Blown	IGCC Oxygen-Blown	CPFBC High Power	CPFBC High Efficiency	PFBC Bubbling Bed	NGCC	PC Plant Supercritical
Gasifier	KRW Air-Blown Fluidized Bed	KRW Air-Blown Fluidized Bed	Destec O_2-Blown Entrained Bed					
Net Power, MWe	385	198	348	431	379	425	323	404
Gas Turbine	Westinghouse W501G	Westinghouse W501D5A	Westinghouse W501G	Westinghouse W501G	Westinghouse W501G	ASEA GT-140P	Westinghouse W501G	
Gas Cleanup, Particulates	Ceramic Candle	Ceramic Candle	Ceramic Candle	Ceramic Candle	Ceramic Candle	Two-Stage Cyclone		ESP
Gas Cleanup, Desulfurization	Transport Reactor with Zn Sorbent	Transport Reactor with Zn Sorbent	Bed with Zn Sorbent	Limestone	Limestone	Limestone		Wet Limestone FGD
Sulfur Recovery	Sulfator	Sulfator	Sulfuric Acid	Landfill	Landfill	Landfill		Gypsum Landfill
Gas Cleanup, NOx	Staged Combustion	Staged Combustion	Staged Combustion	Staged Combustion	Staged Combustion	Combustion Temp. Control	Dry Low NOx Burner	Low NOx Burner

INTEGRATED GASIFICATION COMBINED CYCLE

The KRW gasifier was selected to be the basis for the air-blown fluidized-bed cases because of its inclusion as the basis for the Piñon Pine CCT project. In comparison with the KRW, an oxygen-blown, entrained flow gasifier (Destec) was selected based on its inclusion in the Wabash River CCT project. Additionally, the projected demonstration of hot gas cleanup processes justified inclusion of the developing processes with the IGCC cases. The transport reactor desulfurizer and a ceramic filter are being demonstrated at Piñon Pine as full-scale cleanup processes.

The oxygen-blown Destec gasifier was selected to be representative of entrained flow IGCC applications based on availability of operating data from the Wabash River CCT project. The Destec design is one of the two entrained flow gasifier concepts in the DOE CCT demonstration program; the other includes the Texaco oxygen-blown entrained bed gasification process. Presently both projects are in the operational phase of demonstration.



Wabash IGCC Power Plant

PRESSURIZED FLUIDIZED-BED COMBUSTION

Two classes of pressurized fluidized-bed combustion (PFBC) are evaluated, the bubbling fluidized-bed combustion and the circulating pressurized fluidized-bed combustion (CPFBC).

BUBBLING PRESSURIZED FLUIDIZED-BED COMBUSTION

The systems in a PFBC plant use conventional, proven technology. The ABB Carbon P800 system that forms the basis for the reference plant design is a larger version of the P200 design that was used for the demonstration plant at DOE’s Clean Coal Technology Tidd Demonstration Project and is in operation in other parts of the world. The P800 uses multiples of the P200 components, arranged such that three complements of heat transfer surface derived from the P200 are placed inside the single P800 pressure vessel. The P800 operates at one and one-third times the pressure of the P200 unit. At this higher pressure, three P200 component sets are able to handle four times the air mass flow and heat transfer, yielding four times the power output.

Tidd Plant, Ohio

Circulating Pressurized Fluidized-Bed Combustion (CPFBC)

A fully integrated CPFBC system, at the 15 MWth (7 MWe) proof-of-concept level, is scheduled to be tested at the Power Systems Development Facility in Wilsonville, Alabama. This co-funded research and development program is sponsored by DOE, Southern Company Services, and the Electric Power Research Institute. The first commercial scale APFBC plant has been proposed under the DOE CCT demonstration program for the City of Lakeland, Florida. Under the proposed agreement, Foster Wheeler will design a CPFBC unit for operation at the City of Lakeland's C.D. McIntosh, Jr. Power Plant. Westinghouse Electric Corporation will supply the gas turbine, topping combustor, and ceramic candle filter system.

Circulating pressurized fluid-bed combustion offers the power generator flexibility in the operation of the power block. This flexibility is based on the ability to combust additional coal in the system, above and beyond the quantity required to satisfy the gas turbine's requirement for production of syngas in the carbonizer. To illustrate this flexibility, two separate operational cases have been evaluated and presented in this report. The first case represents a high output case, i.e., 431 MWe at a net efficiency of 45.8 percent on an HHV basis. The second case represents a higher efficiency case, i.e., 379 MWe at a net efficiency of 47 percent on an HHV basis.

Performance Summary

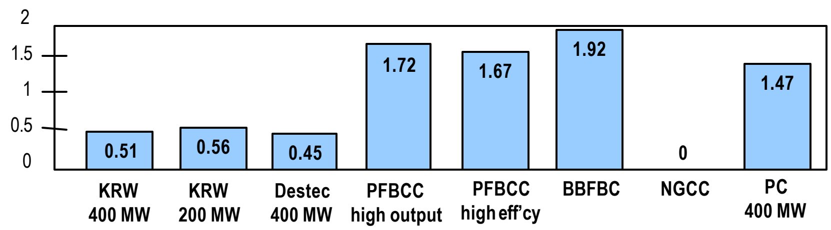
Performance summaries of the power plant concepts are provided in the following table. Heat and material balances were developed for each technology using the ASPEN^{TM} simulation program. Values for the advanced technologies' performance were developed from information based on the CCT demonstration design, field results, and manufacturers' input. Plant capacities were defined to fit potential utility-scale additions for baseload dispatching in the year 2005, that is, approximately 300 to 400 MWe. Therefore, performance analysis for the IGCC, PFBC, PC, and gas turbine plants is representative of plants in a baseload operational mode. The configurations utilize the gasifiers, gas turbines, and gas cleanup concepts that are expected to be commercially offered by 2002, the latest date for a decision to proceed in order to meet the 2005 in-service date. Performance values are based on the use of Illinois No. 6 coal.

Comparison of Performance Summaries

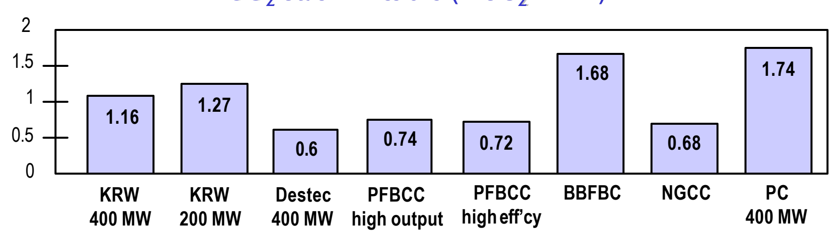
Power Plant Technology	KRW 400 MW	KRW 200 MW	Destec 400 MW	PFBCC high output	PFBCC high efficiency	BBFBC	NGCC	PC 400 MW
Gas Turbine, Gross MW	232.2	116.9	262.6	209.5	206.7	79.5	223.2	NA
Steam Turbine, Gross MW	170.7	92.7	139.4	246.9	195.0	373.8	107.7	427.1
Auxiliary Loads, MW	18.0	11.5	53.8	25.1	22.8	28.6	7.5	23.0
.Net Power, MW	384.9	198.1	348.2	431.3	378.9	424.7	323.4	404.1
Heat Rate, Btu/kWh HHV	7,247	8,086	7,526	7,463	7,273	8,352	6,827	8,520
Efficiency, % HHV	47.1	42.2	45.4	45.8	47.0	40.9	50.0	40.1
Heat Rate, Btu/kWh LHV	7,175	8,006	7,451	7,389	7,200	8,268	6,148	8,435
Efficiency, % LHV	47.6	42.7	45.8	46.2	47.4	41.3	55.6	40.5

ENVIRONMENTAL SUMMARY

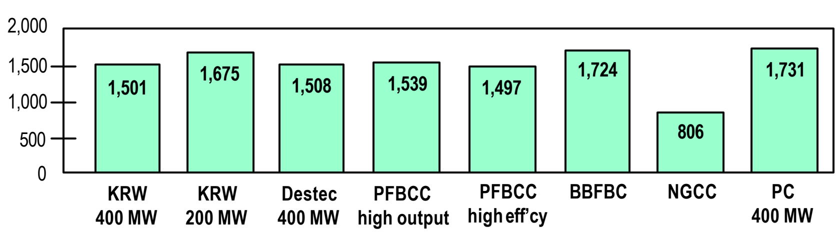
The advanced technology plants described in this report operate with lower emissions than the subcritical PC plant, and in some respects approach, but do not match, the performance of the natural gas burning NGCC. The following bar charts present a comparison of the environmental performance for the technologies evaluated. Emissions performance is presented on the basis of annual output (lb/MWh).



SO_2 Stack Emissions (lb SO_2/MWh)



NOx Stack Emissions (lb NOx/MWh)



CO_2 Stack Emissions (lb/MWh)

Economics

Capital Cost Estimate

Capital cost estimates were developed for the power plant concepts based on adjusted vendor-furnished and actual cost data. The capital costs at the total plant cost (TPC) level include equipment, materials, labor, indirect construction costs, engineering, and contingencies.

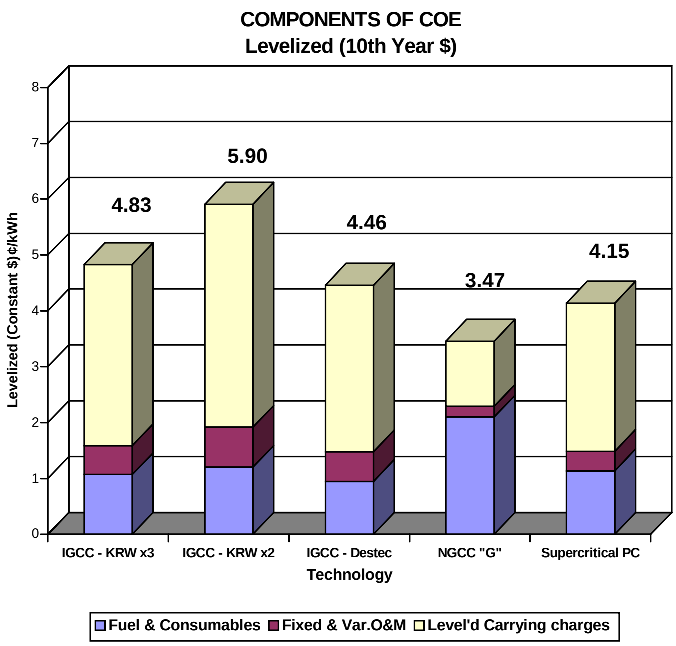
The cost of each major system was based on a reference bottoms-up estimate, establishing a basis for subsequent comparisons and easy modification as the technology is further developed. Total plant cost, or "Overnight Construction Costs" values, are expressed in January 1999 dollars. The estimate boundary limit is defined as the total plant facility within the "fence line," including coal receiving and water supply system, but terminating at the high-voltage side of the main power transformers. Site is characterized to be located in Middletown, south central U.S., and is based on a relative equipment/material/labor cost factor of 1.0. Specific regional locations different from the reference location would result in adjustment to these factors.

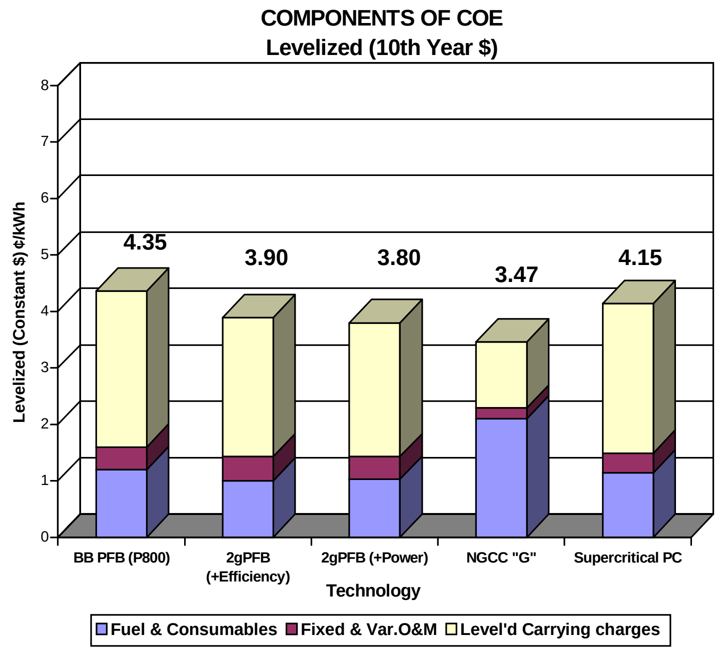
The TPC level of the estimate, as shown on the following table, consists of the bare erected cost plus engineering and contingencies. The engineering costs represent the cost of A/E services for home office engineering, design, drafting, and project construction management services. Costs for engineering services provided by the equipment manufacturers and vendors are included directly in the equipment costs.

Consistent with conventional power plant practices, project contingencies were added to the TPC accounts to cover project uncertainty and the cost of any additional equipment that could result from a detailed design. The contingencies represent costs that are expected to occur. Each TPC cost account is evaluated against the level of estimate detail and field experience to define project contingency. As a result, nominal contingency values of 5 to 30 percent were applied to arrive at the TPC values. These varying percent values result in a composite project contingency rate of about 15 percent. Process contingency was also considered for systems and equipment not considered commercially mature and is intended to cover the uncertainty in the cost estimate.

Production Cost Estimate

The operating and maintenance expenses and consumable costs were developed on a quantitative basis. Operation and maintenance cost values were determined on a first-year basis and subsequently levelized over the 20-year plant book life to form a part of the economic analysis. These are shown as operation and maintenance (O&M) costs (production costs) in the bar charts on the next page. Quantities for major consumables such as fuel and sorbent, and waste disposal were taken from technology- specific heat and mass balance diagrams developed for each power plant configuration. Other consumables were evaluated on the basis of the quantity required using reference data.





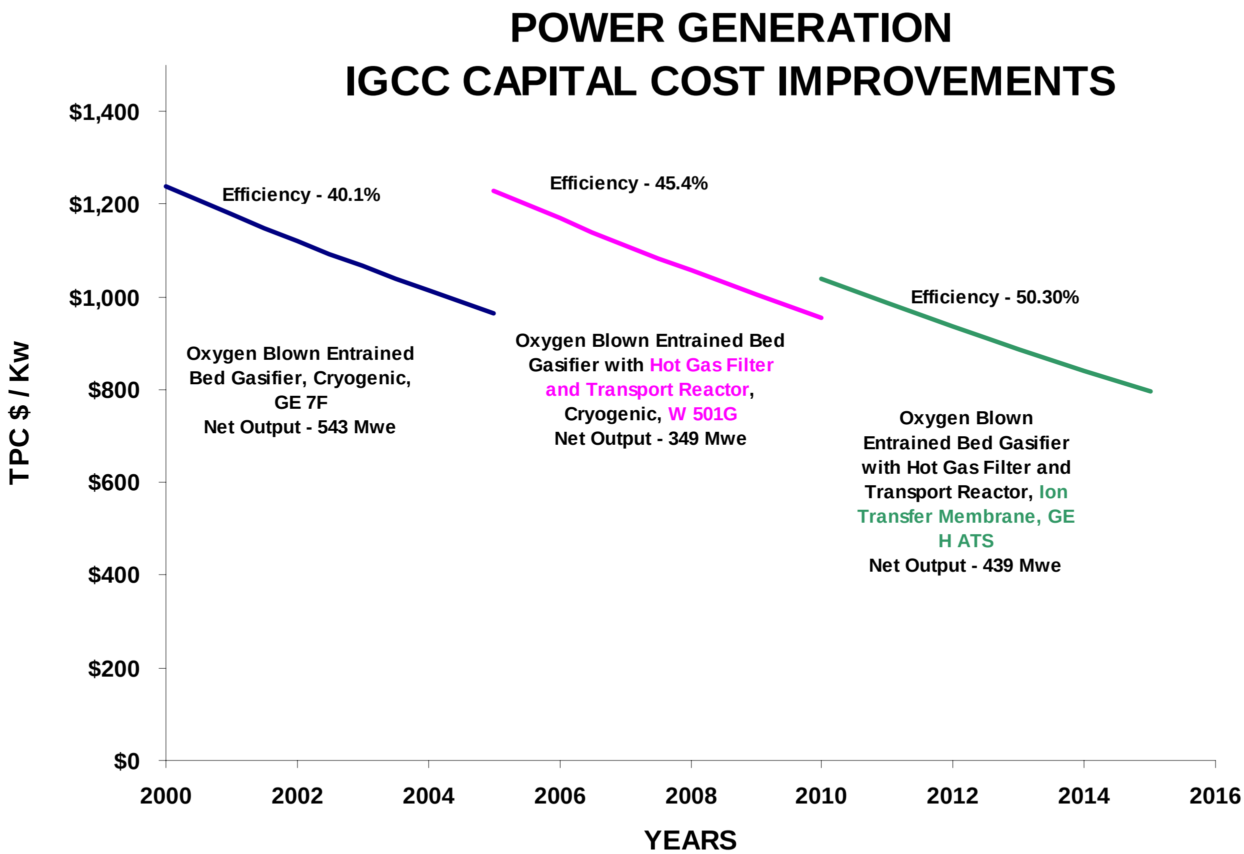
For this analysis the delivered price of coal and natural gas was defined at $1.27/MMBtu and $2.758/MMBtu, respectively.

Operating labor cost was determined on the basis of the number of operators required. Maintenance costs were evaluated on the basis of requirements for each major plant section using relationships of maintenance cost to initial capital cost. The operating and maintenance costs were then converted to unit values of fixed O&M and variable O&M.

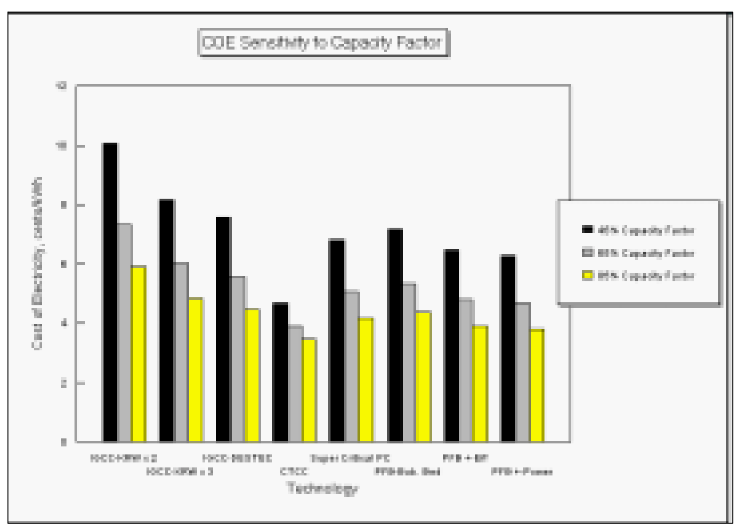
Cost Improvements

Typically, cost improvement potential in advanced coal-based plant configurations will occur with the application of gasification alternatives including air-blown and oxygen-blown, gas cleanup alternatives, and advanced gas turbine technology projected to be available for commercial application in the 2005 to 2010 time frame. As illustrated in the following graph, reductions in capital cost can be expected as the technology matures through successive generations.

Cost and performance improvements can be anticipated with the application of advanced turbine technology presently under development and demonstration by the DOE and its industry partners. Supporting the achievement of capital cost improvements is the present worldwide interest in gasification-based power and co-production projects in refinery applications. For refineries and petrochemical complexes, the gasification projects are focusing on converting low-valued waste streams to valued products including chemicals, energy, and process steam. Several refinery IGCC projects are proceeding where economic conditions are attractive through the use of petrochemical feedstocks such as petroleum coke and deasphalter bottoms.



Risk and Sensitivy Analysis



To provide the decision-maker with an approach to evaluate potential risks, sensitivity analyses for operational parameters have been developed. This bar chart presents the sensitivity on COE from changes in capacity factor, from 45 to 85 percent, for the competing plant designs. As indicated, capacity factor has a significant impact on COE over the range considered typical for these units to be operating. Sensitivity to operational parameters such as capacity factor, heat rate, capital cost, production cost, fuel escalation, and byproduct credit are included in the study.

COMPARISON MODEL

This study uses certain characteristics, assumptions, and parameters that are common to all of the power plant configurations. A simplified comparison model was developed to allow the user to evaluate the effects of changes to these characteristics, assumptions, and parameters using the Microsoft® Excel spreadsheet format. The model allows the user to change limited process and economic variables and see overall effects and impact of the change on each individual power plant. The model will allow the user to change the following parameters:

- Process:
  - Coal flow
  - Coal Btu content
  - Limestone characteristics
  - Limestone stoichiometric ratio
  - Particulate, NOx, and SO_2 removal efficiencies
  - Capacity factors used to calculate the yearly productions of air pollutants

- Economic:
  - Delivered cost of fuel
  - Capital structure
  - Fuel escalation
  - Levelized carrying charge

The model is intended to provide the user with the ability to make small changes to the process. The changes to the process are based on linear relationships between the default settings and the new settings. This will give the user an estimated impact of the change that was made.